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COMBINING ABILITY AND HETEROSIS FOR AGRONOMIC AND YIELD TRAITS IN SOME GRAIN SORGHUM GENOTYPES

Y.M.Y. El Kady, O.A.Y. Abd Elraheem and Heba M. Hafez
Sorghum Research Department, Field Crop Research Institute, ARC, Egypt.

ABSTRACT

The present investigation was carried out to study the performance, heterosis and combining ability in grain sorghum by using line × tester analysis. Twenty-four crosses were obtained by crossing six cytoplasmic male sterile lines (CMS-lines) with four restorers lines (R-lines) at Shandaweel Agric. Res. Station, ARC in 2018 summer season. Thirty five genotypes (24 crosses, their parental lines (10) and the hybrid Shandaweel-305 as check) were evaluated in the summer growing seasons 2019 and 2020 in Shandaweel for days to 50% blooming, plant height, 1000-grain weight and grain yield/plant. The mean squares due to years, genotypes and their partitions crosses, parents and crosses vs parents were highly significant for all studied traits. Also, the interactions between genotypes and their partitions with years were significant or highly significant for all traits. The mean squares due to males, females and their interactions were highly significant for all studied traits. The best female for general combing ability effects (GCA) was ICSB-47 for earliness, BSH-8 for high plant height, BSH-23 for 1000-grain weight and BPOP-15 for grain yield. On the other hand, the best restorer line for GCA effects was RSH-26 for all traits. Meanwhile, the best cross for specific combining ability effects was ASH-23 × MR-812 for earliness, ASH-23 × RSH-26 for high plant height, A POP-15 × Dorado for 1000-grain weight and ASH-8 × RSH-26 for grain yield per plant. Four crosses (APOP-15 ×MR-812, APOP-15× Dorado, ICSA-88003× RSH-26 and ASH-8× RSH-26) had desirable values for heterosis relative to better parent and superior relative to check hybrid for most studied traits. These crosses will be subjected to large-scale field-testing to ascertain their suitability for release as commercial hybrids.

Key words**: Sorghum bicolor (L.) Male sterility, Heterosis, Combining Ability.**

INTRODUCTION

Sorghum (Sorghum bicolor (L.) Moench (2n = 2x = 20) is an important cereal grain and ranks 5th globally after wheat, rice, maize, and barley, in terms of area under cultivation and total production (FAOSTAT 2018). The grains are energy-rich (340 cal per 100 g), high in the levels of protein (11.6%), carbohydrates (73%), and fat (3%) (Sebnie and Mengesha 2018). Grain sorghum is a high-yielding C4 crop that is grown extensively in the semiarid tropics worldwide. Sorghum grain can be used for a variety of purposes such as food, animal feed, and other industrial feedstock to produce liquors, fuel, and chemical materials. Also, sorghum can produce high levels of grain yield in harsh environments (Reddy and Reddy 2019).

Grain sorghum ranks fourth in acreage among cereal crops in Egypt, after wheat, rice and maize. The cultivated grain sorghum area is about 380 thousand feddans producing about 950 thousand metric tons of grains with an average of 2.49 tons/feddan (FAOSTAT 2018). In Upper Egypt, grain sorghum is a major summer crop most present of this area is located in El-Fayoum, Sohag and Assiut governorates. Grain sorghum is adapted to a wide range of stress environments including high temperature, drought, salinity and low soil fertility.

In Egypt, the production of high yielding, with high grain quality sorghum hybrids has become possible with the introduction of several cytoplasmic male sterile and restorer lines. Several investigations have been reported on heterosis, general and specific combining ability and their effects in grain sorghum. Grain yield of some hybrids showed high heterosis over the better parent. Abd El-Halim (2003) found wide variation in heterosis among sorghum crosses, for earliness, plant height, grain weight and grain yield/plant. Mahdy *et al* (2010) stated that most of hybrids were significantly earlier, taller, heavier in grain weight and higher in grain yield compared to their parents and checks. Several cross combinations showed significant positive heterosis for 1000-grain weight, significant negative heterosis for days to heading and good performance. Mahmoud *et al* (2012) found that, some crosses were earlier, taller, more green leaves, higher 1000-grain weight and higher grain yield/plant than the better parent. Also, they found that both additive and non-additive gene effects were important in the inheritance of all studied traits, and that non-additive gene effects played the major role in the inheritance of all the studied traits. Padmashree *et al* (2014) reported that, the GCA effect are mainly due to additive effects and additive x additive interactions while SCA effects may be attributed to non-additive gene effects. Therefore, several sorghum reports indicated that general (GCA) and specific (SCA) combining ability effects for some parental lines (male and female) and hybrids were positive and highly significant for grain yield and its component traits under normal and drought environments. Hassaballa *et al* (2015) reported that, the important roles of both additive and non-additive gene effects in the inheritance of number of days to 50% flowering, plant height, 1000-grain weight and grain yield/plant. El-Sagheer and Bahaa (2020) found that most crosses were earlier, taller plants, higher in number of green leaves, 1000 grain weight and grain yield per plant than the mid and the better parents, which reflecting the importance role of non-additive genetic variance in the inheritance of these traits. Also, high positive heterosis in grain yield and its components were found for more than half of the hybrids. El-Sherbeny *et al*

(2019) found that highly significant variances were found for environments, parents and crosses, lines, testers and lines × testers interaction for all studied characters. Also, they reported that both additive and non-additive gene action played an important role in the expression of studied traits.

In this study attempts were made to identify the best lines from both restorer and cytoplasmic male sterile lines for GCA effects to be included in a crossing program and to estimate the heterosis and SCA effects of the crosses.

MATERIALS AND METHODS

Twenty-four crosses were developed from crossing between six cytoplasmic male sterile (CMS) lines (A-lines) (four of these lines are Egyptian) and four restorer lines (R-lines) (Table 1) at Shandaweel Agric. Res. Station in 2018 season in a line × tester mating design. The 24 crosses and their parents (10 Parents) were evaluated with the check (SH-305) in 2019 and 2020 successive seasons at Shandaweel Agric. Res., Station. The sowing date was on 21, 23 of June in two seasons, respectively. The soil texture is sandy loam. Genotypes were sown in a randomized complete block design (RCBD) with three replications. Each genotype was represented by a single row plot of 4.0 m long, 60 cm apart and 20 cm between hills. Thinning was done after 21 days from sowing date leaving two plants/hill. The recommended cultural practices and plant protection operations for sorghum production were implemented in the proper time.

Data were recorded on five tagged guarded plants from each row. The recorded traits were plant height (cm), 1000-grain weight (g) and grain yield/plant (g) with grain moisture adjusted at 14% moisture. Whereas days to 50% blooming (days) data were recorded on whole row. Data of each year and combined across the two years were subjected to analysis of variance after homogeneity test according to Gomez and Gomez (1984). Line × Tester analysis was done according to Kempthorne (1957) to estimate general combining ability (GCA) effects for females and males and specific combining ability (SCA) effects for hybrids. Homogeneity test for the two seasons data was carried out and consequently combined analysis was performed. Heterosis (H) for better parent and superiority over standard check (SC) was estimated according to the following formula Bhatt (1971).

$$H = \frac{\overline{F}_1 - \overline{B.P}}{\overline{B.P}} x100 \qquad \& \qquad Superiorty = \frac{\overline{F}_1 - \overline{SC}}{\overline{SC}} x100$$

Significance was tested by the appropriate LSD test.

Table 1. Names, origin of the ten parents of grain sorghum genotypes.

NO.	Line	Origin
Restorer -lines (testers) (R-lines)		
1	RSH-26	EGYPT
2	MR-821	ICRISAT
3	ICSR-93002	ICRISAT
4	Dorado	USA
CMS -lines (A-lines)		
5	ASH-8	Egypt
6	ASH-12	Egypt
7	ASH-23	Egypt
8	ICSA-88003	ICRISA
9	ICSA-47	ICRISAT
10	APOP-15	Egypt

RESULTS AND DISCUSSION

The combined analysis across the two years (Table 2). revealed highly significant mean squares due to years (Y), genotypes (G) and their interaction (G × Y) were significant or for all studied traits. Also, the results in Table (3) showed that parents (P) and crosses (C), (males (M), females (F) and M× F) had highly significant mean squares for all studied traits. Results also indicated that highly significant differences were found among parents vs. crosses (P vs C), indicating the presence of significant heterosis. The interaction between both (P) and P vs C with Y were not significant for all traits, except for (P) for grain yield /plant. While the interaction (C × Y) was significant or highly significant for traits studied meanwhile the interaction (F × Y) was significant or highly significant for days to 50% blooming and 1000-grain weight and the interaction (M × F × Y) was highly significant for plant height and 1000-grain weight.

Table 2. Combined analysis of variance for four studied traits across the two years.

SOV	df	Mean squares			
		Days to 50% blooming	Plant height (cm)	1000-grain weight (g)	Grain yield/plant (g)
Years (Y)	1	46.671**	274.286**	2.144**	271.322**
Rep/ Years.	4	2.286	4.429	0.121	0.326
Genotypes (G)	34	48.378**	8737.089**	92.953**	1906.570**
G × Y	34	3.750*	31.815**	2.229**	30.449**
Error	136	2.340	19.164	1.231	15.080

***, ** Significant at 0.05 and 0.01 probability levels, respectively.**

Table 3. Line × tester analysis of variance for four traits across two years.

SOV	df	Mean squares			
		Days to 50% blooming	Plant height (cm)	1000-grain weight (g)	Grain yield/plant (g)
Genotypes (G)	33	49.85**	8921.43**	95.15**	1943.70**
Parents (P)	9	11.308**	1429.93**	55.33**	667.74**
P vs. Crosses	1	153.463**	202105.32**	1706.10**	48165.25**
Crosses (C)	23	19.662**	3453.58**	40.69**	433.35**
Female (F)	5	82.68**	14144.91**	80.82**	938.21**
Male (M)	3	52.689**	1075.06**	114.48**	384.71**
F × M	15	7.759**	365.51**	12.55**	274.79**
G × Y	33	1.670*	32.43*	2.26**	31.28**
P × Y	9	1.573	28.73	1.96	39.52**
P vs. C × Y	1	0.395	0.80	1.17	9.47
C × Y	23	1.763**	35.26*	2.43**	29.00*
F × Y	5	2.786*	15.41	0.25	50.24**
M × Y	3	0.5455	26.23	9.18**	29.59
F × M × Y	15	1.666	43.68**	12.55**	21.81
Error	132	2.33	19.26	1.23	15.12

***, ** significant at 0.5 and 0.01 probability levels, respectively.**

The mean performance of genotypes across two years (Table 4), showed that days to 50% blooming for the parental lines ranged from 68.00 (ICSB-88003) to 74.00 (ICSR-93002) with an average of 70.83 day.

Table 4. Average performance of 24 F_1's and their parents across years for studied traits.

Genotypes	Days to 50% blooming	Plant height (cm)	1000- grain weight (g)	Grain yield / plant (g)
Crosses				
ASH-8 × RSH-26	67.50	226.50	32.00	96.50
ASH-8 × MR-812	71.33	222.00	30.74	85.38
ASH-8 × ICSR-93002	74.50	214.50	30.23	80.00
ASH-8 × Dorado	71.33	213.00	30.00	77.50
ASH-12 × RSH-26	66.17	207.50	32.03	91.50
ASH-12 × MR-812	70.50	213.50	30.33	80.50
ASH-12 × ICSR-93002	70.00	210.00	30.62	77.50
ASH-12 × Dorado	68.00	208.00	29.05	74.00
ASH-23 × RSH-26	69.50	226.00	35.61	72.50
ASH-23 × MR-812	64.00	194.50	34.20	78.50
ASH-23 × ICSR-93002	70.33	209.00	29.58	84.17
ASH-23 × Dorado	67.00	202.50	31.48	85.50
ICSA-88003 × RSH-26	66.50	189.00	29.58	99.50
ICSA-88003 × MR-812	67.83	187.00	27.57	92.50
ICSA-88003 × ICSR-93002	70.00	191.00	26.32	83.50
ICSA-88003 × Dorado	65.00	174.50	26.60	84.00
ICSA- 47 × RSH-26	63.83	213.50	33.18	81.50
ICSA- 47 × MR-812	66.00	204.50	31.20	93.50
ICSA- 47 × ICSR-93002	69.67	211.50	25.66	85.50
ICSA- 47 × Dorado	63.33	188.00	26.53	79.50
APOP-15 × RSH-26	65.67	152.50	33.10	94.00
APOP-15 × MR-812	66.17	163.50	31.57	103.33
APOP-15 × ICSR-93002	69.17	144.00	28.58	90.50
APOP-15 × Dorado	67.00	149.50	33.15	99.67
Average of crosses	67.93	196.48	30.37	86.27

Table 4. Cont.

Genotypes	Days to 50% blooming	Plant height (cm)	1000- grain weight (g)	Grain yield / plant (g)
Female parents				
BSH-8	73.00	116.00	24.87	51.50
BSH-12	71.67	131.50	19.94	46.17
BSH-23	69.67	127.00	22.80	44.00
ICSB-88003	68.00	101.50	19.69	49.50
ICSB-47	70.00	121.00	22.07	39.00
BPOP-15	69.00	111.00	22.87	41.50
Male parents				
RSH-26	69.00	152.50	28.58	67.50
MR-812	73.50	132.50	25.53	57.00
ICSR- 93002	74.00	137.50	26.85	60.50
Dorado	70.50	143.50	27.05	68.83
Average of parental lines	70.83	127.4	24.03	52.55
Check SH- 305	69.67	197.5	30.38	87.17
L.S.D. 0.05	1.73	4.966	1.255	4.401
L.S.D. 0.01	2.26	6.512	1.646	5.769

***, ** Significant and highly significantly at 0.05 and 0.01 probability levels, respectively.**

Whereas, for the crosses 50% blooming ranged from 63.33 (ICSA-47×Dorado) to 74.50 (ASH-8×ICSR-93002) with an average of 67.93 day. In general, most of the F_1 crosses were earlier than their parents. While thirteen crosses were significantly earlier than the check hybrid SH-305. Plant height for the parental lines varied from 101.50 cm (ICSB-88003) to 152.50 cm (RSH-26) with an average of 127.40 cm, while for the crosses it ranged from 144.00 cm (APOP-15×ICSR-93002) to 226.50 cm (ASH-8× RSH-26) with an average of 196.48 cm. Mean of crosses were taller than mean of parents reflecting the presence of hybrid vigor. Also, fourteen crosses were significantly taller than the check hybrid SH-305, and the parental lines Rsh-26 and Bsh-8 gave the tallest crosses compared to the other parental lines.

Regarding 1000-grain weight (Table 4) the means of parental lines were ranged from 19.69 g (ICSB-88003) to 28.58 g (RSH-26) with an average of 24.03 g, and for the crosses it ranged from 25.66 (ICSA-47×ICSR-93002) to 35.61 g (ASH-23× RSH-26) with an average of 30.37 g; mean of crosses was higher than mean of parents. Seven crosses were significantly higher in 1000-grain weight than the check hybrid SH-305. For grain yield, the parental lines varied from 39.00 g (ICSB-47) to 68.83 g (Dorado) with an average of 52.55 g, while, for the crosses it varied from 72.50 (SHA-23×RSH-26) to 103.33 (APOP-15×MR-812) with an average of 86.27 g. Moreover, the data showed that mean of crosses significantly outyielded the mean of parents, indicating the presence of heterosis in grain yield. Seven crosses had significantly outyielded the check hybrid SH-305. The best crosses were (APOP-15× MR-812), (APOP-15× Dorado), (ICSA-88003× RSH-26) and (ASH-8× RSH-26) that gave the highest yield; these crosses can be evaluated on a large scale as promising crosses.

Heterosis

Estimates of heterosis relative to the better parent and superiority relative to check hybrid are presented in Table 5. The data show that sixteen and fourteen crosses were significanty earlier parent than the better parent and the standared check respectively. The best crosses for earlines relative to better parent and ckeck, were ASH-23× MR-812, ICSA-47× RSH-26 and ICSA-47× Dorado that means these genotypes had favorable gene action for earlines. Similar results were obtained by Abd El-Halim (2003), Hafez *et al*. (2009), Mahdy *et al*. (2011) and Saikiran *et al*. (2022). For plant height 14 crosses out of 24 crosses showed positive and highly significant superiority relative to standared check and 9 crosses had negitave and significant superiority relative of the hybrid SH-305.On the other hands, most of the crosses had positive and highly significant heterosis values relative to their better barent, meanig that these crosses had favorable gene action for tallness. Similar results were obtained by Sayed (2003) and El-kady *et al* (2015). For 1000-grain weight, data showed that seven crosses had positive and significant or highly significant superiorty values over the standard check SH-305. With respect to heterosis, 20 crosses had significantly heavier grain more than their better parent.

Table 5. Estimates of heterosis (%) relative to better parent (B.) and superiority (%) relative to check hybrid (SC) of all studied traits across two seasons.

Cross	Days to 50% blooming		Plant height (cm)		1000-grain weight (g)		Grain yield/plant (g)	
	B. parent	SC	B. parent	SC	B. parent	SC	B. parent	SC
ASH-8 × RSH-26	-2.17*	-3.11**	48.52**	14.68**	11.95**	5.33*	42.96**	10.70**
ASH-8 × MR-812	-2.28**	2.38*	67.55**	12.41**	20.44**	1.18	49.80**	-2.05
ASH-8 × ICSR-93002	2.05*	6.93**	56.00**	8.61**	12.60**	-0.49	32.23**	-8.23**
ASH-8 × Dorado	1.18	2.38*	48.43**	7.85**	10.91**	-1.25	12.59**	-11.09**
ASH-12 × RSH-26	-4.11**	-5.02**	36.07**	5.06**	12.07**	5.43*	35.56**	4.97
ASH-12 × MR-812	-1.63*	1.19	61.13**	8.10**	18.84**	-0.16	41.23**	-7.65**
ASH-12 × ICSR-93002	-2.33**	0.47	52.73**	6.33**	14.03**	0.79	28.10**	-11.09**
ASH-12 × Dorado	-3.55**	-2.40*	44.95**	5.32**	7.39**	-4.38	7.51**	-15.11**
ASH-23 × RSH-26	0.72	-0.24	48.20**	14.43**	24.58**	17.22**	7.41**	-16.83**
ASH-23 × MR-812	-8.13**	-8.14**	46.79**	-1.52	33.99**	12.57**	37.72**	-9.95**
ASH-23 × ICSR-93002	0.96	0.95	52.00**	5.82**	10.18**	-2.63	39.12**	-3.44
ASH-23 × Dorado	-3.83**	-3.83**	41.11**	2.53*	16.39**	3.62	24.21**	-1.92
ICSA-88003 × RSH-26	-2.21*	-4.55**	23.93**	-4.30**	3.50*	-2.63	47.41**	14.14**
ICSA-88003 × MR-812	-0.25	-2.64*	41.13**	-5.32*	8.00**	-9.25**	62.28**	6.11*
ICSA-88003 × ICSR-93002	2.94**	0.47	38.91**	-3.29**	-1.99	-13.36**	38.02**	-4.21
ICSA-88003 × Dorado	-4.41**	-6.70**	21.60**	-11.65**	-1.66	-12.44**	22.03**	-3.64
ICSA- 47 × RSH-26	-7.49**	-8.38**	40.00**	8.10**	16.09**	9.22**	20.74**	-6.50**
ICSA- 47 × MR-812	-5.71**	-5.27**	54.34**	3.54**	22.23**	2.7	64.04**	7.26**
ICSA- 47 × ICSR-93002	-0.48	0	53.82**	7.09**	-4.43**	-15.54**	41.32**	-1.92
ICSA- 47 × Dorado	-9.52**	-9.10**	31.01**	-4.81**	-1.91	-12.67**	15.50**	-8.80**
APOP-15 × RSH-26	-4.83**	-5.74**	0	-22.78**	15.81**	8.95**	39.26**	7.84**
APOP-15 × MR-812	-4.11**	-5.02**	23.40**	-17.22**	23.67**	3.92	81.29**	18.54**
APOP-15 × ICSR-93002	0.24	-0.72	4.73**	-27.09**	6.46**	-5.92*	49.59**	3.82
APOP-15 × Dorado	-2.90**	-3.83**	4.18**	-24.30**	22.55**	9.12**	44.79**	14.34**

***, ** Significant at 0.05 and 0.01 probability levels, respectively.**

The best crosses relative to both better parent and check were ASH-23×MR-812 followed by ASH-23×RSH-26 and APOP-15×Dorado. Similar results were obtained by Mahmoud *et al* (2013) and Hassaballa *et al* (2015). They reported that positive and highly significant heterosis was observed for 1000-grain weight. For grain yield per plant, results in Table 5 showed that all the crosses had significantly outyielded their better parents. The best crosses from them were APOP-15×MR-812 followed by ICSA-88003×MR-812 and ICSA-47 × MR-812 and 7 out of 24 crosses were significantly superior to the check hybrid SH-305. The best crosses from them were APOP-15×MR-812, APOP-15 × Dorado and ICSA-88003×RSH-26. In general, the four crosses ASH-8×RSH-26, ICSA-88003×RSH-26, APOP-15×MR-812 and APOP-15× Dorado had desiraable value for heterosis relative to the better parent and superior relative to the check for most studied traits; these crosses should be tested on a large scale in order to release the best of them. Similar results were obtained by Desai *et al.* (1985), Hovny *et al* (2001), Premalatha *et al.* (2006), Hafez *et al.* (2009) and Saikiran *et al* (2022), who found that heterosis was manifested in grain sorghum crosses for grain yield and its components.

General combining ability effects

Estimates of general combining ability (GCA) effects of the parental lines for all studied traits across two years are presented in Table 6. The GCA effects for days to 50% flowering declared that the two female lines ICSB-47 and BPOP-15 and the two R-lines RSH-26 and Dorado showed significant ($p \leq 0.01$) and negative GCA effects. These lines may be considered good general combiners and possess favorable genes for earliness. In addition, for plant height, four female lines (BSH-8, BSH-12, BSH-23and ICSB-47) and one R-Line (RSH-26) had positive and highly significant GCA effects, meaning that they had desirable gene action for tallness. For 1000-grain weight, two female lines (BSH-23; BPOP-15) and two male lines (RSH-26; MR-812) showed positive and significant or highly significant GCA effects that means these lines had favorable gene action for heavy grain weight.

Table 6. Estimates of general combining ability effects of parents for four studied traits across the two years.

Parents	Days to 50% blooming	Plant height (cm)	1000- grain weight (g)	Grain yield/plant (g)
line				
BSH-8	3.236**	22.5208**	0.3719	-1.427
BSH-12	0.736	13.2708**	0.1361	-5.398**
BSH-23	-0.222	11.5208**	2.3469**	-6.106**
ICSB-88003	-0.597	-11.1042**	-2.8556**	3.602**
ICSB-47	-2.222**	7.8958**	-1.2281**	-1.273
BPOP-15	-0.931*	-44.1042**	1.2286**	10.602**
S.E (GCA)	0.402	1.162	0.307	1.142
S. E. (gi-gj)	0.569	1.644	0.434	1.615
Tester				
RSH-26	-1.403**	6.0208**	2.2133**	2.977**
MR-812	-0.292	1.0208	0.5628*	2.679**
ICSR-93002	2.681**	0.1875	-1.8733**	-2.745**
Dorado	-0.986**	-7.2292**	-0.9028**	-2.912**
S.E (gi)	0.328	0.949	0.251	0.932
S. E. (gi-gj)	0.465	1.342	0.355	1.318

***, ** Significant at 0.05 and 0.01 probability levels, respectively.**

Regarding grain yield/plant, the two female lines, ICSB-88003; BPOP-15 and the two male lines RSH-26; MR-812 showed positive and significant ($p \leq 0.01$) GCA effects for grain yield and could be considered good combiners for this trait. It should be indicated that parents with high performance may not transmit their characteristics to their hybrids. These lines had favorable genes for grain yield/plant.

Specific combining ability effects:

The estimates of specific combining ability (SCA) effects across the two years are presented in Table 7. It is clear that the two crosses BSH-8 × RSH-26 and BSH-23 × MR-812 had negative and significant SCA effects for days to 50% flowering; indicating that these crosses represent the best combinations for earliness. On the contrary, two crosses had positive and significant SCA effects for lateness (Table 7).

Table 7. Estimates of specific combining ability effects of 24 crosses for all studied traits across the two years.

Crosses	Days to 50% blooming	Plant height (cm)	1000- grain weight (g)	Grain yield / plant (g)
ASH-8 × RSH-26	-2.264**	1.479	-0.957	8.677**
ASH-8 × MR-812	0.458	1.979	-0.564	-2.142
ASH-8 × ICSR-93002	0.652	-4.687	1.363*	-2.101
ASH-8 × Dorado	1.153	1.229	0.158	-4.434
ASH-12 × RSH-26	-1.097	-8.271**	-0.688	7.647**
ASH-12 × MR-812	2.292**	2.729	-0.737	-3.054
ASH-12 × ICSR-93002	-1.347	0.063	1.982**	-0.629
ASH-12 × Dorado	0.319	5.479*	-0.556	-3.963
ASH-23 × ICSR-92003	3.194**	11.979**	0.677	-10.644**
ASH-23 × MR-812	-3.417**	-14.520**	0.918	-4.347
ASH-23 × RSH-26	-0.056	0.813	-1.263*	6.745**
ASH-23 × Dorado	0.278	1.729	-0.333	8.245**
ICSA-88003 × RSH-26	0.569	-2.396	-0.146	6.648**
ICSA-88003 × MR-812	0.792	0.604	-0.513	0.055
ICSA-88003 × ICSR-93002	-0.014	5.437*	0.673	-3.63
ICSA-88003 × Dorado	-1.347	-3.645	-0.014	-2.963
ICSA- 47 × RSH-26	-0.472	3.104	1.825**	-6.477**
ICSA- 47 × MR-812	0.583	-0.896	1.493*	5.820*
ICSA- 47 × ICSR-93002	1.278	6.937**	-1.611*	3.245
ICSA- 47 × Dorado	-1.389	-9.146**	-1.708**	-2.588
APOP-15 × RSH-26	0.069	-5.895*	-0.711	-5.852*
APOP-15 × MR-812	-0.542	10.104**	-0.597	3.778
APOP-15 × ICSR-93002	-0.514	-8.563**	-1.144	-3.629
APOP-15 × Dorado	0.986	4.354	2.452**	5.760*
S. E. (Sij)	0.805	2.235	0.614	2.283
S. E. (Sij-Skl)	1.138	3.288	0.869	3.229

***, ** Significant at 0.05 and 0.01 probability levels, respectively**

For plant height, five crosses had positive values and significant or highly significant SCA effects and five crosses had negative and highly significant SCA effects. The negative SCA indicate that these crosses represent the best combinations for shortness and vice versa for the positive

SCA effects. Five crosses showed positive and significant SCA effects for 1000-grain weight, indicating that these crosses represent the best combinations for heavy grain yield. For grain yield/plant (Table 7), the results showed that, seven crosses showed significant or highly significant SCA effects; five combinations out of them; ASH-8×RSH-26, ASH-12×RSH-26, ICSA-88003×RSH-26, ICSA-47×MR-812 and APOP-15×Dorado have at least one parent of significant GCA effects. Similar results were obtained by Singh and Singh (1995), Abd-El-Mottaleb (2009), El Kady *et al* (2015, Sayed and Mahdy 2016 and El-Sherbeny *et al* (2019), indicating that a good combination between high and low yielding lines may be due to the interaction between dominant genes from the high yielding line with recessive genes from the low yielding one. From the above data, it can be concluded that, the female lines (ICSB-88003 and BPOP-15) and the restorer lines (RSH-26 and MR-812) had the best GCA effects for grain yield/plant. In addition, they had the best SCA effects when these female lines crossed with the restorer lines (ICSA-88003×RSH-26), (ASH-12×RSH-26) and (ASH-8×RSH-26) are the best crosses and out-yielded the check Shandweel-305. These crosses should be tested on a large scale in order to release the best of them as a commercial hybrid.

REFERENCES

Abd El-Halim, M. A. (2003). Heterosis and line × tester analysis of combining ability in grain sorghum (*Sorghum bicolor* (L.) Moench). M. Sc. Thesis, Fac. of Agric. Assiut Univ., Egypt.

Abd-El-Mottaleb, A.A. (2009). Heterosis and combining ability in grain sorghum (*Sorghum bicolor* L. Moench) under optimum and low level of nitrogen. Ph.D. Thesis, Faculty of Agriculture, Assiut Univ., Egypt.

Bhatt, G.M. (1971). Heterosis performance and combining ability in a diallel cross among spring wheat (*T. aestivum* L.). Aust J Agric. Res. 22: 329-368.

Desai, M. S., K. B. Desai and M.U. Kukadia. (1985). Heterosis and combining ability in grain sorghum. Indian J. of Agric. Sci. 55: 303-305.

El-Kady, Y.M., S.A. Hassaballa, B.R.Bakheit and M.R.A.Hovny (2015). Performance and heterosis of some grain sorghum genotypes under different levels of irrigation. Egypt. J. Plant Breed. 19(6):1819 – 1835.

El-Sagheer, M. E. M. and B. A. Zarea (2020). Genetic components and nature of gene action in some new hybrids of grain sorghum under drought conditions. Asian Research Journal of Current Science. 2(1): 68-79.

El-Sherbeny, A.R., A.G.A, Khaled, M.R.A, Hovney and B. A. Zarea (2019). Combining ability and gene action using Line by Tester analysis on some new hybrids of grain sorghum under drought conditions. PKV Res. J., 49 (1), 118-129.

FAOSTAT (2018). Food and Agriculture Organization of the United Nations Database of agricultural production. FAO Statistical Databases. http ://faostat.fao .org /site /339/default. aspx. Accessed 31 Jan 2019.

Gomez, K.A. and A.A. Gomez (1984). Statistical Procedures for Agricultural Research. John Wiley and Sons. New York. 2nd ed.

Hafez, H.M., A. M. Esmail; M. F. Ahmed and K.M. Mahmoud (2009). Breeding grain sorghum for drought tolerance. 6th International plant breeding conference, Ismailia, Egypt.

Hassaballa, S.A., B.R.Bakheit, M.R.A.Hovny and Y.M. El-Kady (2015). Combining ability studies in grain sorghum (*Sorghum bicolor* (L) Monech) under water stress by using line × tester Analysis. Assiut J. Agric. Sci. (46). (5) 1-10.

Hovny, M.R.A., M.M. El-Menshawi and O.O. El-Nagouly (2001). Combining ability and heterosis in grain sorghum (*Sorghum bicolor* (L.) Moench). Bull. Fac. Agric., Cairo Univ., 52: 47-60.

Kempthorne, O. (1957). Yield stability of single, three way and double cross hybrids, sorghum, Newsletter, 33-59,

Mahdy, E., E., M. A. Ali and A. M. Mahmoud (2010). Agronomic performance, genotype x environment interactions and stability analysis of grain sorghum (*Sorghum bicolor* L. Moench). Asian J. Crop Sci., 2: 250-260.

Mahdy, E.E., M. A. Ali and A.M. Mahmoud (2011). The effect of environment on combining ability and heterosis in grain sorghum (*Sorghum bicolor* L. Moench). Asian J. of Crop Sci. 3(1):1-15.

Mahmoud, K. M., H. I. Ali and A. A. Amir (2013). Line x tester analysis and heterosisin grain sorghum hybrids under water stress conditions. Assiut J. Agric. Sci. 44. (2) 1-38.

Mahmoud, K. M., H. I. Ali and Aml. A. Tag (2012). Performance and stability evaluation of some grain sorghum genotypes. Egyptian J. Agric. Res. 90 (4): 131-146.

Mohammed, A. Sayed and Rasha E. E. Mahdy (2016). Heterosis and genetic parameters in grain sorghum under irrigation and drought stress environments. Egypt. J. Plant Breed. 20 (3):561 – 580 (2016).

Padmashree, N. K. Sridhar and S. T. Kajjidoni (2014). Combining ability studies in forage sorghum (*Sorghum bicolor* L. Moench) for yield and quality parameters. Karnataka J. Agric. Sci. 27 (4) 449-453.

Premalatha, N., N. Kumaravadivel and P. Veerabadhiran (2006). Heterosis and combining ability for grain yield and its components in sorghum [*Sorghum bicolor* (L.) Moench Indian J. Genet., 66(2): 123-126.

Reddy, P.S. and Belum V.S. Reddy (2019). Chapter 4 –History of sorghum Improvement. Wood head Publishing Series in Food Science, Technology and Nutrition 2019, Pages 61-75.

Saikiran, Veldandi D. Shivani, S. Maheswaramma, K. Sujatha, K. Sravanthi S. Ramesh, K. N. Yamini and C. V. Sameer Kumar (2022). Combining ability and heterosis studies in different crop sites for yield and yield contributing traits in sorghum (*Sorghum bicolor* (L.) Moench) Electronic Journal of Plant Breeding 2022.

Sayed, M.A.E. (2003). Heterosis and line x tester analysis of combining ability in grain sorghum (*Sorghum bicolor* L. Moench). M.Sc. Thesis, Faculty of Agric. Assiut Univ., Egypt.

Sayed M. A.and Rasha E. Elsaid Mahdy 2016. Heterosis and Genetic Parameters in Grain Sorghum under Irrigation and Drought Stress Environments. Egypt. J. Plant Breed. 20 (3):561 – 580 (2016.

Sebnie, W and M. Mengesha (2018). Response of nitrogen and phosphorus fertilizer rate for sorghum (*Sorghum bicolor* L.Moench) production in Wag-Lasta area of Ethiopia. Arch. Agric. Environ. Sci. 3:180–186.

Singh, R.B. and D.P. Singh (1995). Agronomic and physiological responses of sorghum, maize and pearl millet to irrigation. Field Crops Res., 42 (2-3): 57-67.

القدرة الائتلافية وقوة الهجين للصفات الزراعية وصفات المحصول في ذرة الحبوب الرفيعة

يوسف محمد يوسف القاضي, عمر ابو الحسن يونس عبد الرحيم و هبه محمد حافظ

قسم بحوث الذرة الرفيعة – معهد بحوث المحاصيل الحقلية – مركز البحوث الزراعية

يهدف هذا البحث إلى دراسة أداء و قوة الهجين و القدرة العامة و الخاصة على الائتلاف في هجن الذرة الرفيعة باستخدام تحليل السلالة × الكشاف .تم الحصول على ٢٤ هجين ناتجة من التلقيح بين ستة سلالات ذات عقم ذكرى سيتوبلازمى واربع سلالات معيدة للخصوبة في محطة البحوث الزراعية بشندويل في موسم ٢٠١٨م .وقد تم تقييم الأربعة والعشرون هجينا وآباؤها (عشرة أباء) با لإضافة لهجين المقارنة شندويل-٥ ٣٠ في مزرعة بحوث جزيرة شندويل بسوهاج- مصر في موسمي ٢٠١٩-٢٠٢٠م م.لدراسة عدد ايام التزهير , وطول النبات , ووزن ال ١٠٠٠- حبة وكذلك محصول الحبوب . وكان متوسط المربعات الراجع للسنوات والتراكيب الوراثية وتفعالاتها والآباء والهجن مقابل الاباء عالية المعنوية لكل الصفات المدروسة. كما أن التفاعلات بين التراكيب الوراثية وتقسيمها مع السنوات كانت معنوية او عالية المعنوية لكل الصفات ، وكان متوسط المربعات الراجع للاباء والأمهات والتفاعل بينهما عالى المعنوية لكل الصفات المدروسة. كانت أفضل الأمهات لتأثير القدرة العامة على التآلف (GCA) هي ICSB-47 لصفة التبكير، BSH-8 لصفة طول النبات، BSH-23 لصفة وزن الالف حبة و B POP-15 لصفة محصول الحبوب للنبات وافضل الاباء ذات قدرة عامة على التآلف هى RSH-26 لكل الصفات المدروسة. وفي الوقت نفسه ، كانت أفضل الهجن ذات قدرة خاصة على التآلف هي ASH-23 x NR-812 لصفة التبكير فى التزهير، ASH-23 x RSH-26 لصفة طول النبات ، POP-15 x Dorado لوزن ١٠٠٠ حبة و ASH- 8 x RSH-26 لمحصول الحبوب لكل نبات. وقد اظهرت اربع هجن (APOP-15 × MR-812، APOP-15 × Dorado، ICSA-88003 × RSH-26 و ASH-8 × RSH-26) قيم مرغوبة لقوة الهجين بالنسبة لأفضل الآبوين وللتفوق على الهجين القياسي لمعظم الصفات المدروسة. وهذه الهجن ستخضع لاختبارات ميدانية واسعة النطاق للتاكد من ملاءمتها لإطلاقها كهجن تجارية.

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